Cost to Earth – Guide to create Sustainability Magic Quadrant In Supply Chain Management

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Imagine a world where Circular economy is a reality.

How would we measure Supply Chains operating in the world of Circular economy; distinguishing Sustainable firms from those with non-sustainable firms?

Can a Single Model encompass all the parameters to measure Sustainability?

What relevant factors should such model encompass?

January 6,

We have all studied about Air pollution, Water pollution & Land pollution in our primary school.

Can this serve as a primary reference to create a Sustainability Model? And in turn a Magic Quadrant for any product Manufactured?

Cost to Earth – Land Pollution

Abstract: Sustainability in any product manufactured is rarely measured; general lack of consensus on how to measure is a hindrance. This research article proposes a model to measure Sustainability using 2 measures, Production Centric '**Circularity Score**' and Consumer Centric '**Cost to Earth**' as a universal model for every product manufactured and sold. The core tenets of Decomposable, Recyclable and Reusable are used to classify components/ Bill of Materials (BOM) albeit only those that remains extractable at the end of life (EOL). These EOL components are called as eBOM (end of life/extractable Bill of Materials). In a simple world, **eBOM** are handled by waste or sewage departments. Often manufacturers (or their agents) take back part of the eBOM which is valuable to them, to integrate within their supply chain (**Internal - reuse**); where it is not valuable to manufacturers themselves, often others, related/unrelated to the original manufacturer recover eBOM to be introduced within their own supply chain (**External - recycle**) while the rest are discarded (**decompose**). Above 2 measures when printed on the product sold gives sustainability score. And using these measures how manufacturers can drive the procurement & production plans, to set YoY targets, measure KPIs and thus improve.

Article

Keywords: Bill of Material (BOM), End of Life (EOL), Sustainability Magic Quadrant, Circularity RACI, Cost to Earth, Decompose, Recycle, Reuse

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1. Introduction

Circular Supply Chain detailed in **Figure [1] o**ffers a vision, however, much of the re- search focus has gone into classifying the type of products and their reintroduction method- ologies [1]. Namely apparel, toilet paper, CPG, electronic, furniture, plastics, automobiles, glass and depending on each type of product their reintroduction within supply chain have created diverse nomenclature such as reengineer, reuse, remanufacture, refurbish, recycle, etc. [2] [3]. Creating a diverse permutation and combination of the applicable approaches for the appropriate product types.

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Figure 1: EU Circular Economy Model [6]

Systematic way of procuring materials that were at the end of life discarded and extracted for production measures the **circularity targets YoY** (strategy set by a company) & manufacturing/packaging a product using those discarded components provides a production plan (**operational**) realized, which can be **measured & tracked** using **IT systems** throughout its **lifecycle** and beyond. The role of different structures and stakeholders for this to work seamlessly although important is hardly considered; a **Circularity RACI** matrix of how an end consumer, waste/sewage department, manufacturer/distributor can play a vital role is articulated. Outside of the recycle logo no other indicators are visible on the product, which should help compare 2 products from sustainability standpoint selling the same content [4]. Stage wise implementation within **IT systems**, **role** played by different **stakeholders** and **consumer choice** with clear cut **Score** are all addressed in this article.

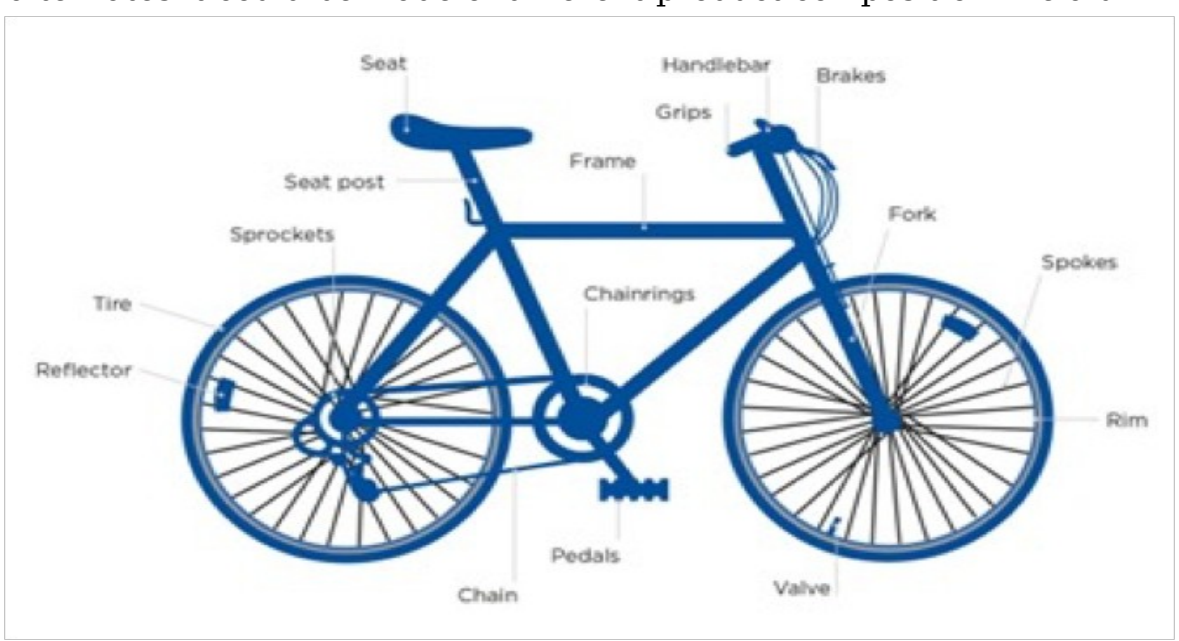
2. Materials and Methods

2.1. Model Core Components – Bill of Material (BOM) & Decompose Recycle Reuse (DRR)

BOM refers to the components that go into making a particular product (a Recipe for Finished Goods - FG or Work in Progress - WIP). Within Supply Chain ecosystems, when we consider **forecasting** a product quantity's we naturally break it down (disaggregate) to the BOM, the components that go into making a particular product. Sometimes, alterna- tives can be used in manufacturing the same product, hence **forecasting and procuring materials** (BOM) to produce an end item can be long and tedious, depending on the avail- ability (market conditions). The lead time to procure & produce BOM components by

different **suppliers influence the decision** of which variant of a similar product gets produced/manufactured.

For example, in the below **Figure 2** of producing a bicycle, we have at Level 1 – two wheels, one handle, one frame, and one seat. Each of those have their own dependent units (BOM). When we look at alternates it could be made of different product composition like aluminum or carbon



fiber for the handle or the frame, rubber or leather seat and wheel with tires of varying dimension. So, the final product combinations become more diverse as the ingredients (BOM) that go into making the final product increases, especially when they have alternates.

Figure 2: Cycle BOM

eBOM – end of lifecycle (extractable) Bill of Material. Components of a product, packaging or parts thereof that remain extractable at the end of life which needs to be handled, this is **a new terminology** coined as part

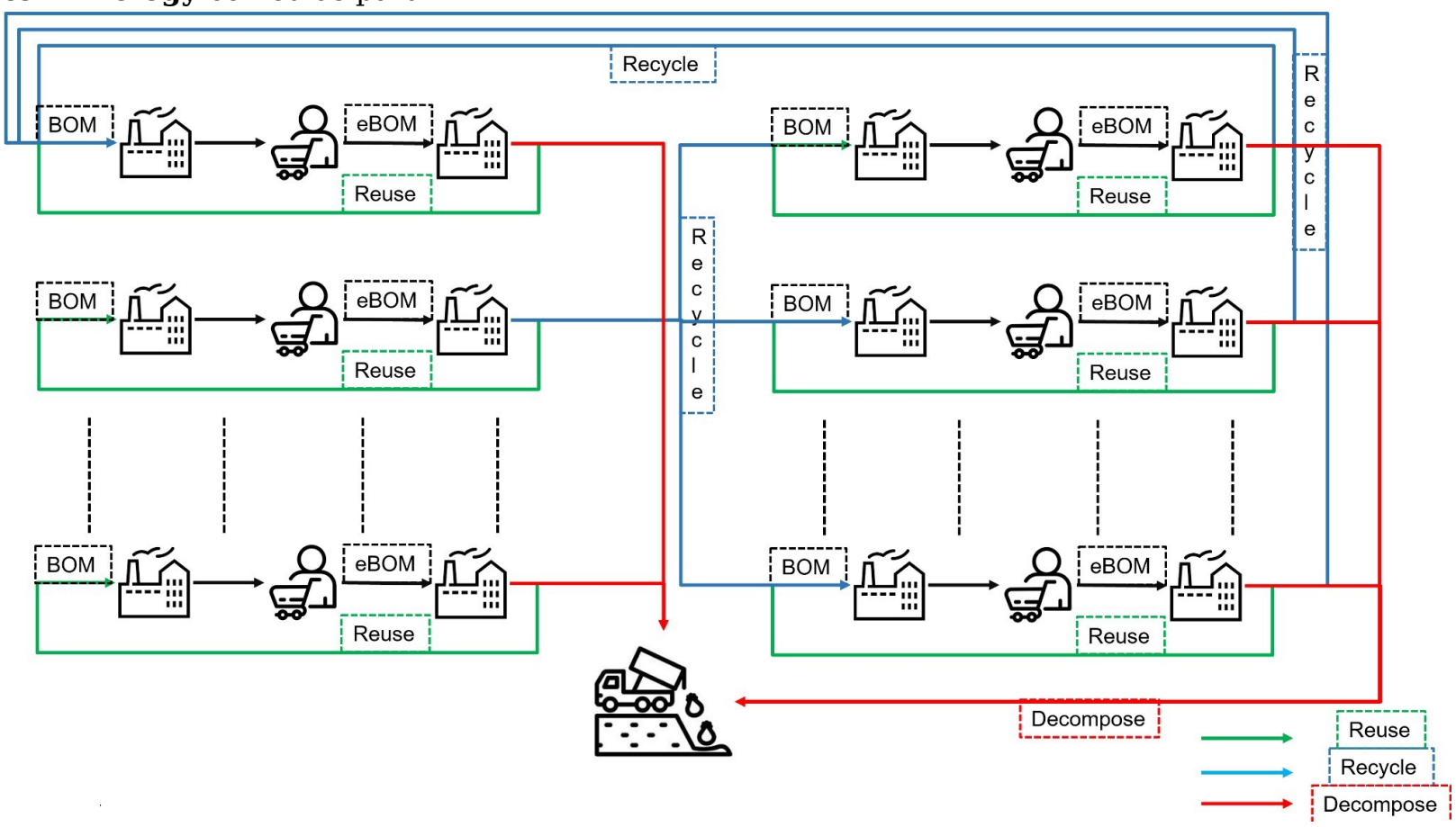


Figure 3: Decompose, Recycle & Reuse

of the BOM Sustainability Model.

Decompose, Recycle & Reuse - Consumers use the product until the end of its life, which may be the warranty period, sometimes discarding it before or after. **Unconsumed Extractable components** remain, which must be discarded after the usage of the product (end of life), sometimes it can be packaging, or it could be the product itself not useful to the consumer anymore. The set of components that remain extractable at the end of life are classified as **eBOM** extractable/end of life Bill of Material (eBOM).

In a simple world, these components (eBOM) are handled by waste or sewage departments. Often manufacturers (or their agents) take **back part of the eBOM** which is **valuable** to them, to integrate (reintroduce) within their supply chain by creating **necessary structures for recovery**; where it is not valuable to manufacturers themselves, often others, related/unrelated to the original manufacturer find value in these eBOM components and recover them to be introduced within their supply chain and for the remaining where no value found they are discarded**. Simply put eBOM can be reused (original/internal supply chain), recycled (external supply chain), decomposed/discarded (no supply chain). DRR – Decompose, Recycle or Reuse** in its simple

representation is shown in **Figure 3.**

2.2. Sustainability Scores – Circularity Score, Cost to Earth (CtE

Circularity Score – a **Production centric score** that takes into account BOM com- ponents part of the SKU (Product) to be manufactured and sold. This score is computed based on the eBOM (Extractable or end of lifecycle Bill of Material) that become new BOM for manufacturing or packaging a new product. Simply put it is **the percentage of BOM components that are recycled & reused in a fresh production/manufacturing process.** Score is calculated using only the extractable components, ignoring the ones that get consumed & not expected to be handled from end-of-life standpoint.

If a 25% of BOM components used in the production/manufacturing are recycled or reused, with 75% being virgin (first time usage) the **circularity score will be 25**.

This model considers volume as the base for these calculations and not the weight, allowing for a mix of multiple components both virgin and recycled on a daily basis based on operational feasibility.

Cost to Earth (CtE) – a Consumption centric score (based on Sold to Country); it is a fundamental measure represented as **Space * Time**, derived from the sum of **volume** of the eBOM components and **years to decompose(max)** of the particular eBOM, based on the end-of-life (DRR) proposal adopted in the **Sold to Country** for the eBOM. Ignoring

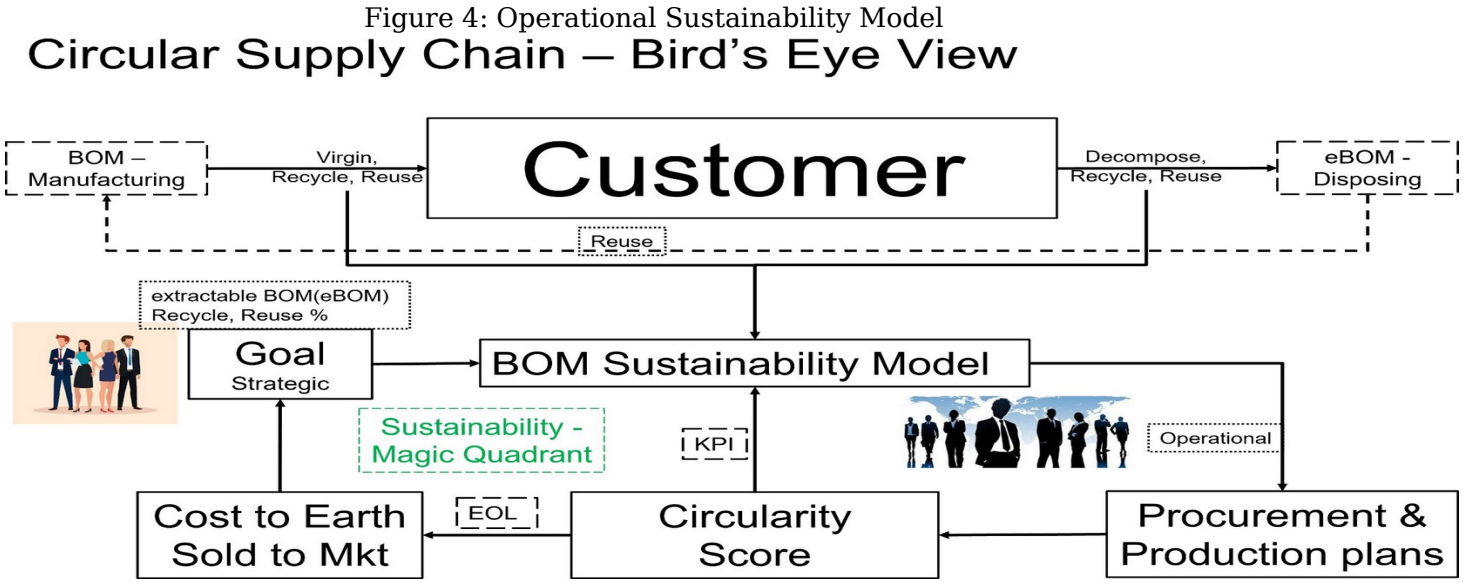
the recycled or reused eBOM components which are expected to be integrated within the supply chain, with the rationale that the eBOM earmarked for decomposition requires a **predefined space/volume and for a given no of years** in the country as there is no recycle or reuse possible; hence a need to allocate predefined **space** for a predefined **time**.

To facilitate necessary infrastructure for Circular economy and helping **Sold to Country** with the right practices to adopt and also allocate space for **End-of-Life handling**.

2.3. Supply Chain Tenets – Production & Procurement Plan

Strategic Goal set by a company feed into the Sustainability Model to give operationally viable **Procurement and Production Plans** as articulated in **Figure 4**.

Figure 4: Operational Sustainability Model



Strategic goal, is a Company goal set by Manufacturing companies in this Sustainability Model, for ex: DRR – 30-30-40 (current financial year) to 20-30-50 (Next financial year) out- lines a **long-term strategy for businesses to implement**. These goals can be set at Man- ufacturing plant level (production centric) and sold to country level (consumption centric); which corresponds to improving the circularity score by aligning **Procurement/Sourcing strategy with Production** using equipment, tool that are conducive to include a higher mix of recycle/reuse BOM and setting up necessary structures to improve recycle/reuse ef- ficiencies for the eBOM and bring down the decomposable (virgin components) eBOMs. Its main target is **aimed at improving the Circularity Score & Cost to Earth (CtE).**

Business planners, who oversee various aspects of demand and supply planning, base their **sourcing** and **production** decisions on this goal. These decisions influence the components (mix) included in the BOM for manufacturing, '**KPI**' when measured at plant level provides a bottom-up achieved against the top-down goal set comparing the **planned versus actual** outcomes for a given product (or product family) level at production and the point of sale (sold to country), offering critical insights into the **effectiveness of sustainability efforts**.

2.4. IT Implementation – Stages of Adoption

Radical changes however meaningful are rejected by market forces, unless there is a clear plan in ease of adoption. Hence there are 3 stages proposed as noted in **Figure 5**.

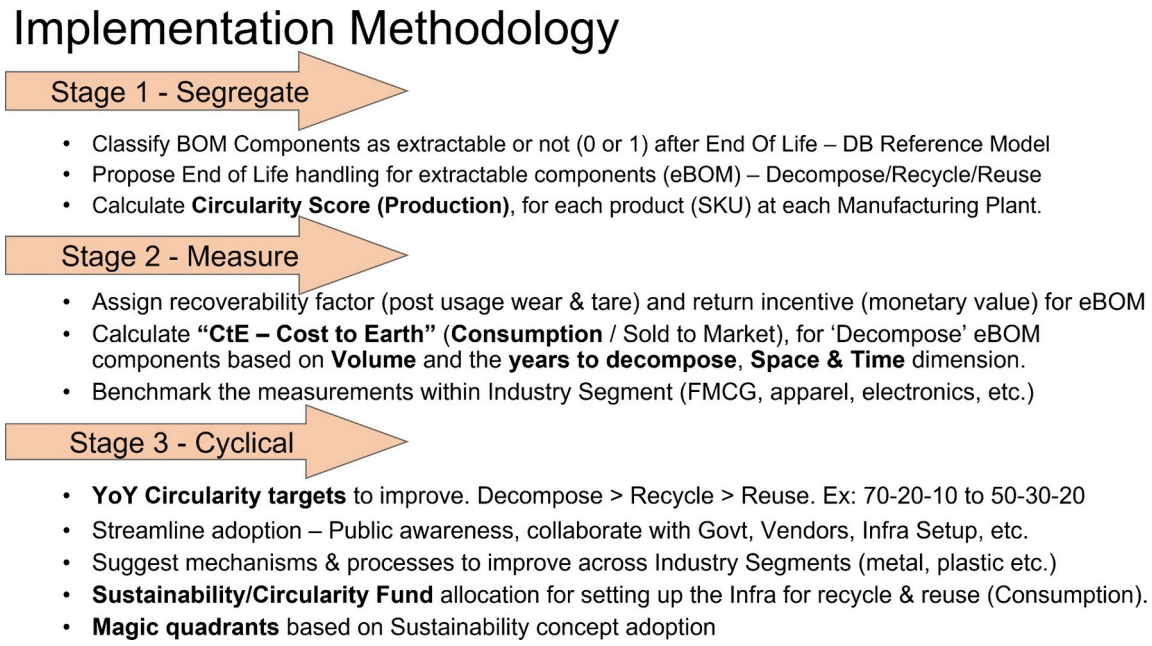
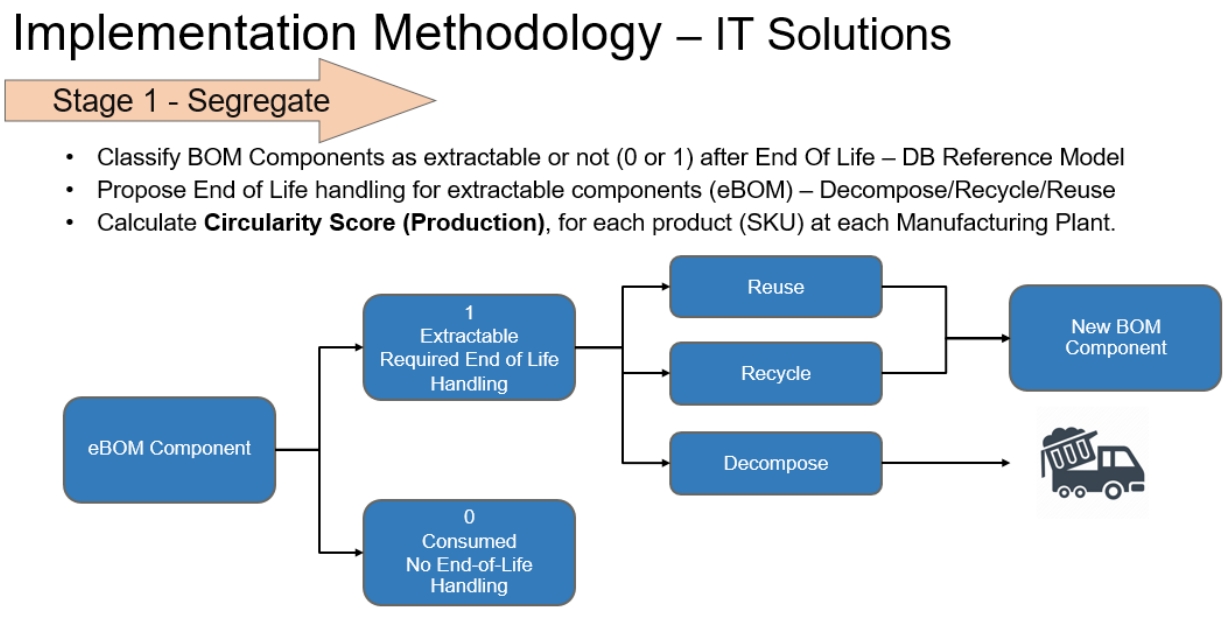

Implementation Methodology
Stage 1 - Segregate
• Classify BOM Components as extractable or not (0 or 1) after End Of Life – DB Reference Model
• Propose End of Life handling for extractable components (eBOM) – Decompose/Recycle/Reuse
• Calculate Circularity Score (Production), for each product (SKU) at each Manufacturing Plant.
Stage 2 - Measure
• Assign recoverability factor (post usage wear & tare) and return incentive (monetary value) for eBOM
• Calculate "CtE – Cost to Earth" (Consumption / Sold to Market), for 'Decompose' eBOM components based on Volume and the years to decompose, Space & Time dimension.
• Benchmark the measurements within Industry Segment (FMCG, apparel, electronics, etc.)
Stage 3 - Cyclical
• YoY Circularity targets to improve. Decompose > Recycle > Reuse. Ex: 70-20-10 to 50-30-20
• Streamline adoption – Public awareness, collaborate with Govt, Vendors, Infra Setup, etc.
• Suggest mechanisms & processes to improve across Industry Segments (metal, plastic etc.)
• Sustainability/Circularity Fund allocation for setting up the Infra for recycle & reuse (Consumption).
• Magic quadrants based on Sustainability concept adoption

Figure 5: IT Implementation Methodology

Stage 1: Segregate In the initial phase of our approach, I propose three straight, simple & yet forward-thinking steps:

•**Classification** of BOM Components Based on **Extractability** Post-End of Life: As- sign a Boolean/binary value (Yes or No, or 0 or 1) to determine whether BOM components can be extracted after their end of life. This step establishes a reference model to identify materials that remain intact and are not consumed by the end user. Despite potential wear and tear or erosion and corrosion from usage, these components are available (extractable) for disposal at the product's end of life.

•**End of Life Definition** for Extractable Components: Classify each eBOM compo- nent as decomposable, recyclable, or reusable (DRR) for all extractable components. Thus, ensuring each component's final disposition is appropriately decided based on the Sold to Country, aligning with sustainability goals.



•**Circularity Score** calculation (Production): depending on the eBOM finding its way as BOM

for a new product manufactured, circularity score is computed.

Stage 2: Measure Introduce a "recoverability factor" and offer monetary incentives for the return of eBOM components to encourage recycling and reuse.

- **Recoverability Factor**: This applies to extractable components, assessing how much of the component remains intact after wear and tear for extraction. For example, food and beverage containers are expected to maintain their structural integrity, though they can also be damaged. Metals may rust, and rubber items like tires might retain only 80% of their original volume due to usage. This factor helps gauge the level and feasibility of recovery.
- **Monetary Incentives**: Assign a value to components that can be reused within their supply chain. The incentive could be based on unit, weight, or volume, such as 10 cents for a returned beer bottle or a set amount for a kilogram of a specific grade of plastic or metal, depending on the BOM type. Model proposal is to assign **1% of the average selling price**. Alternative economy.
- **Cost to Earth**, CtE (Consumption): Measure the impact of extractable eBOMs based on their volume and the years they take to decompose.
- Volume: The space a component occupies in the earth (soil/water/air) for the need to be decomposed.
- Years to Decompose: The duration required for a component to decompose, depending on its material type.

Stage 3: Cyclicity Repeat the process and improving YoY, market over market, component over component.

- Establish **yearly eBOM targets** to enhance the DRR Score, aiming for a shift from components marked for decomposition to those more amenable to reuse. For instance, adjust the DRR allocation from 70-20-10 in 2025 to 50-30-20 by 2027. This means reducing the proportion of components designated for decomposition from 70% to 50%, thereby increasing recycling and reuse within the supply chain of each by 10%.
- Recommend **strategies across industry segments**: Move beyond industry-specific analysis to a more cross industry approach. For example, a particular grade of plastic used in bicycles, food packaging, automotive or electronic can have similar end-goals post recovery. Utilize **Magic Quadrants for Sustainability**: To gauge the cyclical nature of supply chains and identify genuinely green industry players, use the Circularity Score & Cost to earth, CtE metric for comparison among competitors.

- Foster **Streamlined Adoption**: Collaborate with governments, vendors, and other in- stitutions to overcome the adoption challenges of earmarking BOM components for recycling or reuse, which requires appropriate infrastructure.
- Raise **Public Awareness**: Address the hurdles of collection and segregation that impede the long-term objectives of a cyclical supply chain. Engage the end consumer by promoting awareness through various media outlets, underlining the importance of sustain- ability practices. Incentives

proposed in the 2nd stage, should help efforts of recollection.

2.5. Circularity RACI – Stakeholders

Implementing a **transfer of ownership** for products and their components (eBOM) at their **end-of-life** involves creating specific channels to streamline the collection, dismantle

and segregation of components(eBOM); in order to seamlessly adopt the recycling, reuse, and decomposition processes within the supply chain arm.

Safe disposal is considered for biomedical waste and other hazardous goods; there is much left to be done if the manufacturers are held accountable.

RACI (Responsible, Accountable, Consulted, Informed) framework streamlines this ap- proach and helps in adoption:

Responsible (R): This role is typically assigned to a third-party agency or the existing waste handling department within the government, or it could be a new partnership estab- lished by the manufacturer in the country where the goods are shipped & sold. A clearly defined and designated owner for this should help in recovery facilitated by incentivizing, even if recovery expectations from the end consumer are set.

Accountable (A): The manufacturer or a third-party logistics provider (3PL) who oversees the sales, production and/or distribution of the product should be made accountable for end-of-life handling. This entity is a Bill to organization in supply chain terminology.

Consulted (C): Government agencies in the country where the product is sold should be consulted to ensure compliance with local regulations and also seek support to make it feasible. This creates the sense of ownership and helps local government play a key role on its impact of the community.

Informed (I): The general public, who are made aware of different steps taken and how they can contribute with clearly incentive on offer broadcasted through popular media to not only participate in proposed end-of-life processes for products & its eBOM but also benefit from it.

This structured approach is designed based on the DRR model, tailored to the operational standards of the company, the country of sale, and the sales channel involved. Manufacturers are encouraged to assign a RACI matrix for each product (or product family) and for each eBOM to ensure clear responsibilities and streamline end-of-life management.

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2.6. Benefits

The CtE (Cost to Earth) - BOM sustainability model offers a range of benefits, aiming to enhance environmental accountability and circularity across industries:

- **Track and Trace**: Utilizes IT systems for comprehensive tracking of component usage throughout their lifecycle, fostering circularity by monitoring end-of-life stages.
- **Simplified Metric**: Provides a simplified method for assessing sustainability by seg- regating the production side with consumption side, from an end-of-life perspective. This facilitates

benchmarking across companies within the same sector and encourages the adop- tion of green practices through assessment and incentives.

- **Standardization**: Promotes universally applicable and replicable models, ensuring consistency in sustainability practices without room for varied interpretations.
- **Targets**: Assists in setting specific goals for companies, taking into account local demo- graphics and environmental considerations. Maturity of the company and the infrastructure of a country will help accelerated adoption and drive pathbreaking results.
- **Counterfeits** are avoided as the extractable components have a sustainable plan of action designed by the Responsible & Accountable parties to handle post usage.
- **Magic Quadrant**: Enables a comparative analysis of companies based on their sus- tainability efforts, extending beyond traditional metrics like CO2 emissions and the use of greener fuels.
- **Consumer Consciousness**: Raises awareness among consumers about a company's environmental impact, guiding them towards making informed choices and influencing in- dustry standards and market sentiments.
- **Antidumping**: Encourages shared responsibility for end-of-life management, aiming to prevent the improper disposal of waste materials.
- **Producer Consciousness**: Focuses on the assessment and long-term impact of prod- ucts, fostering a deeper understanding of their environmental footprint.
- **Alignment with Country**: Supports the development of models that are adaptable to specific demographic and environmental conditions, promoting global applicability with localized relevance.

3. Results

As part of the new framework (BOM Sustainability model) proposed, which helps **mea- sure the sustainability of each product manufactured** and also provide score to be it printed on the product for consumer to make informed decision (and also help build con- sumer consciousness) we have 2 different scores – **Circularity Score** (Production centric) & **Cost to Earth** (Consumption/Sold to Country).

To help improve on the above score or make it achievable **YoY sustainability targets** are set and to support it we have an optimization model (analytical method) that helps set the long-term **Production and Procurement Strategy and operationalize it into a daily plan** using Decompose, Recycle, Reuse (DRR) as core tenets for the Bill of Material (BOM) of choice.

In the below **Figure 6** we have all the calculations consolidated into one excel; with the left half having the '**Circularity Score**' and the right half focusing on the '**Cost to Earth**'.

Figure 6:

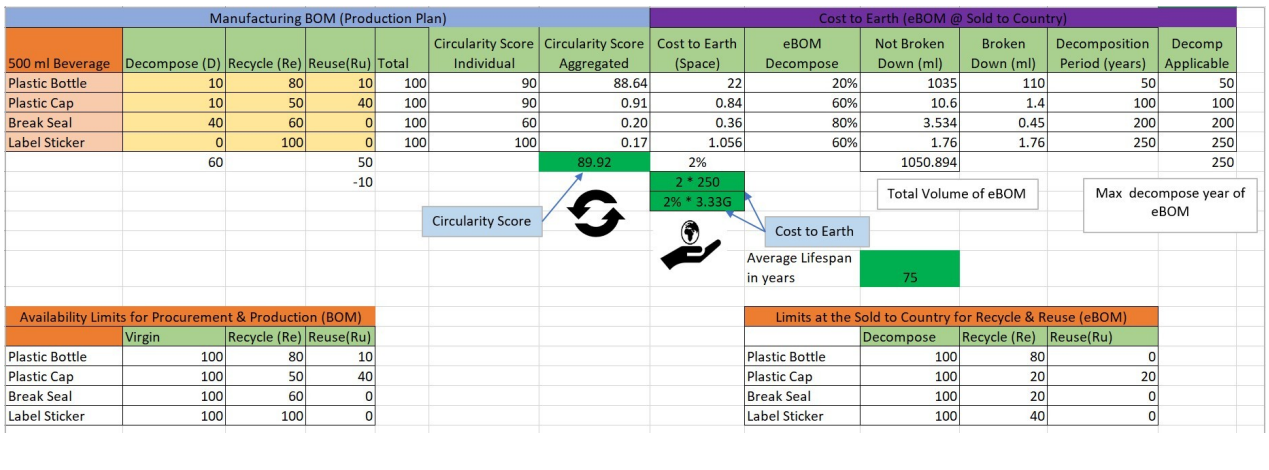
We are taking a 500ml beverage product manufactured and sold in a country.

Let us take one score at a time and analyze how we compute them.

3.1. Circularity Score

This score is based on the extractable components that go into making it. So, the beverage itself is ignored (captured as 0 in the Database/IT System) but the components in which it is packaged (captured as 1) and delivered is taken into consideration. Above has been taken a simplistic example, which can realistically extend to any type of manufactured product a razor, mobile, shoe, apparel, automobile etc.

Figure 7:



Manufacturing BOM (Production Plan)							Cost to Earth (eBOM @ Sold to Country)					
500 ml Beverage	Decompose (D)	Recycle (Re)	Reuse(Ru)	Total	Circularity Score Individual	Circularity Score Aggregated	Cost to Earth (Space)	eBOM Decompose	Not Broken Down (ml)	Broken Down (ml)	Decomposition Period (years)	Decomp Applicable
Plastic Bottle	10	80	10	100	90	88.64	22	20%	1035	110	50	50
Plastic Cap	10	50	40	100	90	0.91	0.84	60%	10.6	1.4	100	100
Break Seal	40	60	0	100	60	0.20	0.36	80%	3.534	0.45	200	200
Label Sticker	0	100	0	100	100	0.17	1.056	60%	1.76	1.76	250	250
	60		50			89.92	2%		1050.894			250
			-10				2 * 250					
							2% * 3.33G					

Circularity Score

Cost to Earth

Total Volume of eBOM

Max decompose year of eBOM

Average Lifespan in years 75

Availability Limits for Procurement & Production (BOM)			
	Virgin	Recycle (Re)	Reuse(Ru)
Plastic Bottle	100	80	10
Plastic Cap	100	50	40
Break Seal	100	60	0
Label Sticker	100	100	0

Limits at the Sold to Country for Recycle & Reuse (eBOM)			
	Decompose	Recycle (Re)	Reuse(Ru)
Plastic Bottle	100	80	0
Plastic Cap	100	20	20
Break Seal	100	20	0
Label Sticker	100	40	0

Figure 8: BOM Sustainability Model

1. 500ml drink sold in Plastic Bottle

Assume the end-of-life/extractable Bill of Material (eBOM) components include the **plastic bottle** itself, the **plastic cap** to hold the contents inside, **break seal** to ensure that the contents don’t spill if the cap were to open accidentally & the **label** which holds the vital information for consumer to choose.

We have limits of how these components are sourced, whether they are virgin, freshly produced or procured, made of recycled materials or reused (brought back).

Table 1 has the limits in procuring different BOM components as one of the 3 type namely Virgin, recycle or reuse.

Table 1: Limits for Procurement & Production (BOM)

Availability Limits for Procurement & Production (BOM)		
Virgin	Recycle (Re)	Reuse (Ru)

Plastic Bottle	100	80	10
Plastic Cap	100	50	40
Break Seal	100	60	0
Label Sticker	100	100	0

Let us try to maximize the reuse option, as this is the eBOM component produced (discarded from) by the product sold by the company. Second, we prioritize the recycled component or component produced by recycle materials. When the 100% of requirements are not satisfied by either of these components, recycle & reuse, then we will procure the product produced from virgin components.

Linear Programming Formulation Decision Variables:

Pv, PRe, PRu (*Virgin, Recycled, Reused Plastic Bottles*)

Cv, CRe, CRu (*Virgin, Recycled, Reused Plastic Caps*)

Bv, BRe, BRu (*Virgin, Recycled, Reused Break Seals*)

Lv, LRe, LRu (*Virgin, Recycled, Reused Label Stickers*)

Objective Function:

Minimize the use of virgin materials is done using the Equation (1), where *Pv* are the plastic bottle manufactured using virgin, *Cv* are the Plastic caps manufactured using virgin components and *Bv* Break seals manufactured using virgin components and *Lv* Label stickers manufactured using virgin components

$$Z = Pv + Cv + Bv + Lv$$

Constraints:

Material Balance Constraints:

$Pv + PRe + PRu = 100$ (*Plastic Bottle*)

$Cv + CRe + CRu = 100$ (*Plastic Cap*)

$Bv + BRe + BRu = 100$ (*Break Seal*)

$Lv + LRe + LRu = 100$ (*Label Sticker*)

Equations mentioned in the Material Balance Constraints include *Pv , PRe, PRu* which are the plastic bottle manufactured using virgin, recycled and reused components, *Cv , CRe, CRu* are the Plastic caps manufactured using virgin, recycled and reused com- ponents and *Bv , BRe, BRu* Break seals manufactured using virgin, recycled and reused components and *Lv , LRe, LRu* Label stickers manufactured using virgin, recycled and reused components

Recycling and Reuse Constraints:

$PRe \leq 80,\ PRu \quad 10$ (*Plastic Bottle*)

$CRe \leq 50,\ CRu \quad 40$ (*Plastic Cap*)

$BRe \leq 60,\ BRu = 0$ (*Break Seal*)

$LRe <= 100,\ LRu = 0$ (*Label Sticker*)

Non-Negativity Constraints:

Pv, PRe, PRu, Cv, CRe, CRu, Bv, BRe, BRu, Lv, LRe, LRu ≥ 0

Table 1 has 10 reuse plastic bottles retrieved for manufacturing, 80 composed of recycled materials, while 100 virgin components are available for manufacturing. Similarly other remaining components. Using analytical method (simple linear program) we will solve the procurement quantities as show in **Figure 7**.

The Circularity score calculated can be either based on the broken down or non-broken- down volume of a product using the values captured in the **Table 2** which comes upto be 90.04 & 89.92 respectively as visible in **Figure 7**.

Manufacturing BOM (Production Plan)							
500 ml Beverage	Decompose (D)	Recycle (Re)	Reuse(Ru)	Total	Circularity Score Individual	Circularity Score Brokendown	Circularity Score Aggregated
Plastic Bottle	10	80	10	100	90	87.14	88.64
Plastic Cap	10	50	40	100	90	1.11	0.91
Break Seal	40	60	0	100	60	0.24	0.20
Label Sticker	0	100	0	100	100	1.55	0.17
	60		50			90.04	89.92
			-10				

Circularity Score

Availability Limits for Procurement & Production (BOM)			
	Virgin	Recycle (Re)	Reuse(Ru)
Plastic Bottle	100	80	10
Plastic Cap	100	50	40
Break Seal	100	60	0
Label Sticker	100	100	0

Figure 9: Circularity Score - Plastic Bottle

Table 2: Product Volume

Type 500 ml Beverage	Not Broken Down (ml or c^3)	Broken Down (ml or c^3)	Decomposition Period (years)
Plastic Bottle	1035	110	50
Plastic Cap Break	10.6	1.4	100
Seal Label Sticker	3.534	0.45	200
	1.76	1.76	250
Glass Bottle	1200	283	1000*
Crown/cap Label	4.53	0.83	200
Sticker	1.76	1.76	250
Can Soda	650	36	200

2. 500ml drink sold in Glass Bottle

Using the same logic, we calculate the the Circularity score calculated based on the broken down and non-broken-down volume of Glass bottle using the values captured in the **Figure 8** comes upto be 99.63 & 99.85 respectively.

3. 500ml drink sold in Aluminum Can

Using the same logic, we calculate the the Circularity score calculated based on the broken down and non-broken-down volume of Glass bottle using the values captured in the

Manufacturing BOM (Production Plan)							
500 ml Beverage	Decompose (D)	Recycle (Re)	Reuse(Ru)	Total	Circularity Score Individual	Circularity Score Brokendown	Circularity Score Aggregated
Glass Bottle	0	20	80	100	100	99.09	99.48
Crown/Cap (Aluminium)	20	80	0	100	80	0.23	0.30
Label Sticker	50	50	0	100	50	0.31	0.07
	70		80			99.63	99.85
			10				

Circularity Score

Availability Limits for Procurement & Production (BOM)			
	Virgin	Recycle (Re)	Reuse(Ru)
Glass Bottle	100	20	80
Crown/Cap (Aluminium)	100	80	0
Label Sticker	100	50	0

Figure 10: Glass Bottle

Figure 9 comes upto be 90 for both.

Manufacturing BOM (Production Plan)							
500 ml Beverage	Decompose (D)	Recycle (Re)	Reuse(Ru)	Total	Circularity Score Individual	Circularity Score Brokendown	Circularity Score Aggregated
Can (Aluminium)	10	90	0	100	90	85.81	89.76
Label Sticker	10	90	0	100	90	4.19	0.24
	20		0			90.00	90.00
			-20				

Circularity Score

Availability Limits for Procurement & Production (BOM)			
	Virgin	Recycle (Re)	Reuse(Ru)
Can (Aluminium)	100	90	0
Label Sticker	100	90	0

Figure 11: Can

3.2. Cost to Earth

This score is based on the extractable components that gets discarded at the end of the life of a product. It can be the product itself, like a mobile or an automobile or a cloth or a shoe or their packaging material like food packet or shampoo container. This helps in articulating the components that are discarded and what is their end-of-life handling mechanism.

1. 500ml drink sold in Plastic Bottle

Manufacturing BOM	Cost to Earth (eBOM @ Sold to Country)					
500 ml Beverage	Cost to Earth (Space)	eBOM Decompose	Not Broken Down (ml)	Broken Down (ml)	Decomposition Period (years)	Decomp Applicable
Plastic Bottle	22	20%	1035	110	50	50
Plastic Cap	0.84	60%	10.6	1.4	100	100
Break Seal	0.36	80%	3.534	0.45	200	200
Label Sticker	1.056	60%	1.76	1.76	250	250
	2%		1050.894	113.61		250

2 * 250
2% * 3.33G

Total Volume of eBOM

Max decompose year of eBOM

Cost to Earth

Average Lifespan in years: 75

Limits at the Sold to Country for Recycle & Reuse (eBOM)			
	Decompose	Recycle (Re)	Reuse(Ru)
Plastic Bottle	100	80	0
Plastic Cap	100	20	20
Break Seal	100	20	0
Label Sticker	100	40	0

Figure 12: Cost to Earth - Plastic Bottle

This depends on the Sold to Country, prevalent policies in the country, and also the sellers involvement. So the limitations for effective reintroduction to supply chain via Reuse or Recycle are captured in the bottom of the **Figure 10**. Top half as the fields Decompositio period in years, Broken down and not broken down volume of the eBOM and then the calculations of

1. **eBOM Decompose** – which is based on the limits captured in the bottom half of the **Figure 1 0** (Table). It is sum of the percentage of recycle & reuse that can be employed.

2. **Cost to Earth** (Space) – which is a broken down volume multiplied by the eBOM Decompose percentage, giving the space required for the product.

Using the above information mentioned in the **Figure 10** the **Cost to Earth** (CtE) calculated for the plastic bottle comes to be 2 * 250, where 2 is the percentage of the broken down represented as it takes 2% of its original volume with 250 representing the maximum years for the decomposition of all the particles combined, which essentially says for it to be decomposed fully and give back the full space it requires 250 years.

Same value when taken into average life span set as 75 years in the **Figure 10**, the measure

Cost to Earth (CtE) comes to be **'2% * 3.33G'**. Referring to generations

2. 500ml drink sold in Glass Bottle

Cost to Earth (CtE) calculated based on the limits set in the bottom half of the **Figure 11** comes upto be '**1% * 13.33G**'.

Whopping 13 generations to free up the space.

Manufacturing BOM	Cost to Earth (eBOM @ Sold to Country)					
500 ml Beverage	Cost to Earth (Space)	eBOM Decompose	Not Broken Down (ml)	Broken Down (ml)	Decomposition Period (years)	Decomp Applicable
Glass Bottle	14.15	5%	1200.00	283	1000	1000
Crown/Cap (Aluminium)	0.0083	1%	4.53	0.83	200	200
Label Sticker	1.584	90%	1.76	1.76	250	250
	1%		1206.29	285.59		1000

1 * 1000
1% * 13.33G

Total Volume of eBOM

Max decompose year of eBOM

Cost to Earth

Average Lifespan in years: 75

Limits at the Sold to Country for Recycle & Reuse (eBOM)			
	Decompose	Recycle (Re)	Reuse(Ru)
Glass Bottle	100	0	95
Crown/Cap (Aluminium)	100	99	0
Label Sticker	100	10	0

Figure 13: Cost to Earth - Glass Bottle

3. 500ml drink sold in Aluminum Can

Cost to Earth (CtE) calculated based on the limits set in the bottom half of the **Figure 12** for an aluminium can discarded at the end of life comes upto be '**0% * 3.33G**'. Negligible amount less than 1% remains for 3 33 Generations

Manufacturing BOM	Cost to Earth (eBOM @ Sold to Country)					
500 ml Beverage	Cost to Earth (Space)	eBOM Decompose	Not Broken Down (ml)	Broken Down (ml)	Decomposition Period (years)	Decomp Applicable
Can (Aluminium)	0.36	1%	650.00	36	100	100
Label Sticker	1.584	90%	1.76	1.76	250	250
	0%		651.76	37.76		250

0 * 0
0% * 3.33G

Total Volume of eBOM

Max decompose year of eBOM

Cost to Earth

Average Lifespan in years: 75

Limits at the Sold to Country for Recycle & Reuse (eBOM)			
	Decompose	Recycle (Re)	Reuse(Ru)
Can (Aluminium)	100	99	0
Label Sticker	100	10	0

Figure 14: Cost to Earth Can

Like mentioned earlier it is a measure of **Space * Time** dimension, derived from **the sum of volume of the eBOM** components and **years to decompose(max)** of the particular eBOM, based on the end-of-life (DRR) proposal adopted in the Sold to Country for the eBOM. Rationale being that it requires a **predefined space/volume in the earth** (air/water/land) and for a **given no of years** in the country as there is no recycle or reuse possible; hence a need to allocate space time dimension.

3.3. Production & Procurement Plans

The CtE (Cost to Earth) - BOM sustainability model offers a range of benefits, aiming to enhance environmental accountability and circularity, where does supply chain fits into the puzzle. It fits in when we make the sourcing (procurement) strategy to be decided based on the potential suppliers available or adding new suppliers so as to be measured and improved YoY targets, DRR BOM components, which reflects the sourcing mix available for production; considered in a production plan; accommodating in different batches or shifts with or without change over required from a machine/equipment/tool setup for combining this mix, essentially accommodating the recycled or reused components might be a factor in the Production Plan to be executed at the Shop floor in the daily scheduled plan as part of scheduling and sequencing operations.

Hence this circularity score bakes into the production environment essentially the Manufacturing Plant supporting the strategy and operationalizing it, with the right equipment, machine, tool & labor. Taking more of **recycled or reused products** if not already the original way of operating (For ex: cold drink or beer, already reuses the bottle most of the geographies if not all), can be set **plant specific** and then added onto other plants. Hence the circularity score is measured for the product manufactured at a specific plant.

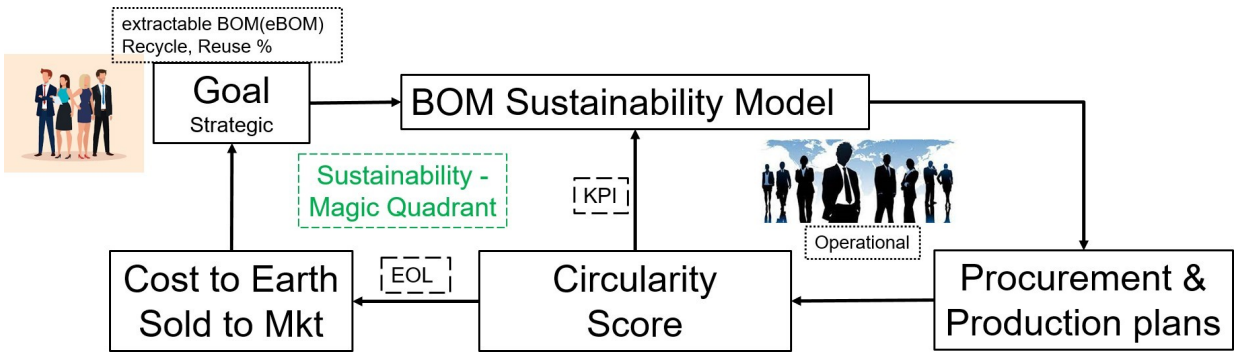


Figure 15: Supply Chain Planning

Figure 13 is read as a sequence of activities taking place; starting from top left where a **Strategic Goal** is set for the company in the form of decomposed (virgin), recycled & reused BOM components (ex: 50-30-20) by the C Suite executives, which sets the limits (procurement & production) within the model showcased for calculating the **Circularity Score & Cost to Earth**. Will provide the real time Procurement & Production plans which can be operationalized at different Manufacturing Plants (across geographies) level which when executed provides the operational KPI, say plan was to include 30% recycled component and 20% reused component for a particular BOM, but because of market condi- tions you were able to get 40% recycled component while 5% of your reuse component got delayed cause of shipping challenges, will give you the operationally executed as 45-40-15. Giving the **circularity score realized** at the Manufacturing plant. and then looking at the Sold to Country, we can set different organizational policy based on the ease of operation and recycle, reuse methods well set based on the government and infrastructure conduciveness and dependent on the presence of the organization which can be offloaded, if need be, artic- ulated clearly under the title **Circularity RACI**. This information would drive consumer choice and conscious, leading to better strategies at organization, Industry and government policies.

4. Discussion

Cost to Earth – BOM Sustainability Model proposed being a novel way of operationaliz- ing the Sustainable Development Goals set by UN articulated in **Figure 1 4** into a ground reality aided by IT Supply Chain applications.

This can be applied to any product manufactured and sold. Just doesn't have to be a FMCG, which could be a good place to start but also furniture, electronics, automotive, healthcare – BOMs can get complex.

Model has scope for inclusion and enhancement such as

1. Efficiency of Recycling grade as 25%, 50%, 75% and 100% equivalent to that of Reuse in Sold to Country. So that using just the recycle logo, the bare minimum is not achieved and go furt

Figure 16: UN Sustainable Development Goals [5]

a) 25% efficient if only recycling logo is included

b) 50% efficient for creating infrastructure (tie-ups) for collection & disposal – Decompose, Recycle or Reuse

c) 75% efficient for Incentivizing & Tracking the collection. Proposal is that it should be 1% of the product price

d) 100% efficient if reintroduction as a new BOM is defined

2. Virgin, recycle mix can be included into the model with slight modification of having one additional attribute (such as 20% Virgin, 80% recycled – for 100 products)

3. Packaging such as Bubble wrap, Gift Wrap or any other value-added service provided at the retail store (or last mile delivery) inclusion.

4. This model (land model) can be extended to include the **air & water** components by taking into as a function of input & output. How much clean water or air is included and how much of waster is created. **Manufacturing level, Distribution Center or Retail Store** level. Even to the flows such as transportation for Co2 emissions

5. Comprehensive scores could enable to Magic Quadrant on other parameters such as green energy production and consumption, Circularity Score, Cost to Earth, Co2 emissions etc.

6. Allocating designated space for decomposed materials might help in retrieval in case of innovative technological breakthrough in biochemistry facilitating retrieval and reintro- duction.

7. Carbon credits can be given for net neutral companies

8. Companies can be mandated via the Corporate Social Governance Fund to aid improve the recycling efficiency to reduce the **Cost to Earth**.

Not all great things can be achieved at once. There are lot of things that can be taken into consideration such as

- Material Circularity Indicator (MCI), how many times can we recycle or reuse before we decompose
- Rate of decomposition of products is not considered of the product
- Safe disposal as such for biochemical products unconsumed such as food, sanitary, medicines, toiletries etc. would be a natural extension

Conclusions

My grandmother used to collect the milk packet in 1990’s which when returned were incentivized at 1% the purchase price of the milk. There were several at good practices adopted in previous century, having long term ecological benefits, have been let gone keeping business viability at the center to buy cheap and sell cheap, which in turn lead to buy bulk and sell bulk.

When a score is printed on a product based on Sold to Country, we as a consumer are bound to make informed decisions and help companies adopt better practice and recognize those who are

making efforts in going an extra mile in case of ecological preservation.

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